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GENERATION AND TESTS ON AQUEOUS FOAM STABILIZED WITH CMC-7HP

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U. S. NAVAL CIVIL ENGINEERING LABORATORY
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GENERATION AND TESTS ON AQUEOUS FOAM
STABILIZED WITH CMC-7HP

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by

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ABSTRACT

Rapid deterioration of ice surfaces during the late spring and early summer in the polar regions presents difficulties in the use of ice surfaces for scientic stations and airfields. Tests by contract with Onondaga Associates, Inc., using aqueous foam indicated its potential benefit as a protective covering for ice. Difficulties with the Onondaga Associates foam generator led to its modification and further tests by NCEL.

These tests were conducted at Port Hueneme, California, because it closely approximated a field situation with the higher relative humidities encountered at a coastal installation where the foam would be used and yet had a high incident solar radiation which approximated the curing conditions under which the foam had originally been tested. Although the sand base on which it was tested had limitations, these were not considered significant when compared with the curing conditions desired. The average solar radiation for a 24-hour period at Port Hueneme was found to closely approximate that at a location such as Point Barrow during spring thaw. During these tests, the expansion ratio achieved using a formulation recommended by Onondaga Associates was less than one-half that recommended for maximum lasting ability; at the end of 8 days, the foam was completely collapsed and had never acquired the dry cellular texture of the Contractor's laboratory tests. In addition to being low, the expansion ratios achieved were variable.

Traffic tests with a 1½-ton truck showed that the moist foam would stick to the tires until they were covered, leaving the sand bare. Dried foam was crushed beneath the tires. From these tests, it was concluded that the aqueous foam made of the recommended formulation with Mearlfoam-5 and 1.75 percent CMC-7HP stabilizer was difficult to generate and required a precise control for mixing and foaming.

INTRODUCTION

The above freezing ambient temperatures and high solar radiation found in most polar regions during late spring, summer, and early fall cause rapid deterioration of ice surfaces. In order to develop and maintain year-round ice areas, the ablation and deterioration of the ice surface must be kept at a minimum. Almost any insulating material placed on the ice surface will delay ablation. For this purpose, aqueous foams were laboratory and field tested and were found to protect ice surfaces from ablation and deterioration on a small scale.[1] This document describes the generation of aqueous foam stabilized with CMC-7HP, its lasting ability and its trafficability.

BACKGROUND

Developmental work by Onondaga Associates, Inc., on a foamed insulation for the protection of airfields[2] showed that protein base aqueous foams would protect ice surfaces during periods of melt. During these investigations, a laboratory model foam generator was constructed, and cold chamber tests were conducted to determine its foaming ability at low temperatures. Further investigations[1] resulted in the development of an aqueous foam which, in laboratory tests, was capable of withstanding temperatures from -40 to +50 F and which appeared to last indefinitely at these temperatures. In this condition, the foam was highly cellular, dry, and very lightweight. The foam in these tests consisted of a solution of Mearlfoam-5 in water stabilized with carboxymethyl cellulose (CMC) and aluminum acetate. Field tests were then conducted at Point Barrow, Alaska, using the original foaming equipment and the weakest but most easily generated of the CMC stabilized foams, CMC-7LP.[1] The surface of the foam did not cure as much nor as fast as it had during laboratory cold chamber tests, nor did the foam dry completely as it had in the laboratory tests. This was attributed to the high relative humidity encountered as a coastal environment.

The Point Barrow trials revealed two major problems in the development of the aqueous foam for protecting ice surfaces. First, the foam generator did not have an adequate capacity, was too fragile for field use, and was not capable of producing foam with CMC-7LP stabilizer at an adequate rate; and second, the CMC-7LP stabilized foam provided only short life protection (2 to 3 weeks) of the ice curing thaw.[3]

At the conclusion of the Point Barrow tests, it was determined that no further work should be done on foam formulations until another generator, which could rapidly field-generate foam, was available. In addition, it was determined that the formulation of 1.75 percent CMC-7HP stabilized foam recommended by Onondaga Associates (Table I) should

be field evaluated as it had appeared to produce the strongest and most stable of any of the CMC stabilized foams during laboratory tests.

The incident solar radiation and relative humidity of the laboratory and Point Barrow test sites were reviewed in order to choose a comparable test site for the next generation tests. The two radiations used in the laboratory tests were 0.41 and 0.78 gm cal/cm^2 min. At Point Barrow the daily average total incident solar radiation averaged about 0.37 gm cal/cm^2 min with a range from 0.22 to 0.69 gm cal/cm^2 min. Relative humidity at Point Barrow for May and June was generally found to be between 82 and 93 percent.[4] Solar radiation and relative humidity values for Port Hueneme, California, were found to average above 0.50 gm cal/cm^2 min and 60 percent respectively for daylight hours.

Port Hueneme, California, was then chosen as the test site as it closely approximated a field situation with the higher humidities encountered at Point Barrow and the higher solar radiation obtained during the laboratory tests, and yet it was easily accessible. In additio-

1. The foam would generally be used in a coastal situation during a high humidity season.

2. The high incident solar radiation of the laboratory tests had apparently contributed significantly to the drying of the foam surface.

Even so, it was recognized that there were certain limitations to the Port Hueneme beach site since the firm sand base did not simulate the moist cold ice base of earlier tests. To counteract the dryness of the sand, to simulate the wetness of the ice, and to minimize the tendency to draw moisture from the foam, the sand was thoroughly wet down immediately prior to application of the foam. The 30 F or so difference in base temperature between the sand and ice, and the difference in air temperature at the sites were considered subordinate factors in the curing of the foam.

For these preliminary tests, it was considered that these limitations were overshadowed by the presence of factors which were believed to provide the desired curing reaction - that of the foam setting up and drying into a cellular structure, which was never achieved at Point Barrow.

FOAM GENERATION AND TESTS

Based on the foam tests by Onondaga Associates, Inc.,[1] it was determined that a foam generator was needed which would generate

foam at some recommended expansion ratio at a more rapid rate than the Onondaga Associates machine. This expansion ratio was determined from earlier tests[1] to be from 8:1 to 12:1. The foaming rate was to be 50 square feet per minute of a 4-inch-thick foam from a liquid of 21,000 centipoise maximum viscosity.[3]

The generator was to be sled-mounted to allow for direct application of the foam to the ice surface. To accomplish continuous foam generation, a nursery style supply was planned in which large quantities of foam solution would be prepared mechanically and supplied to the generator as needed. The batch generator, however, was to be used to test small batches rather than for continuous production. Consequently, each batch was hand mixed in 55-gallon drums, with the assistance of the generator, immediately prior to foaming.

Description

The stabilizer and liquid foam were mixed by recirulating the mixture and by mechanical agitation. The mixture was foamed using a Penberthy injector with compressed air, a refining section, and a centrifugal pump, all connected in series. Improved foaming was to be achieved with this arrangement through the use of a larger piping, regulated pump speeds, and the use of the centrifugal pump for better homogenization of the liquid and air. A complete description of the batch generator can be found in the Appendix.

During preliminary tests of the generator, using only unstabilized Mearlfoam, a maximum expansion ratio of 10:1 was achieved as compared to a maximum expansion ratio of 35:1 accomplished with the Onondaga Associates generator.[2] With the addition of stabilizer to the foam, the expansion ratio at Port Hueneme was reduced (Figure 1) although the specified generation rate was maintained.

The expansion ratio of the stabilized foam varied considerably in the recommended 1.75 percent CMC foam. In this foam, the expansion ratio varied from 2.49:1 to 5.35:1. Because the CMC and aluminum acetate were difficult to get into solution, it is felt that these higher expansion ratios occurred when all of the CMC and aluminum acetate was not dissolved. For the tests on the foam durability and trafficability, it was desired to have a variety of expansion ratios. Because this was not feasible using the recommended formulation, the percent of stabilizer in the foam solution was varied between 0.75, 1.25, and 1.75 percent in a standard 6.7 percent foam solution[5], which resulted in the expansion ratios shown in Table II.

Procedure

Test areas were constructed on beach sand above the high tide line

at Port Hueneme, California. The sand was leveled and immediately prior to applying the foam, the sand was thoroughly saturated with fresh water. Confinement of the plots with 2 x 2's was necessary to obtain a uniform thickness and retain the semi-liquid foam. Six 10- by 10-foot plots, three 1-3/4 inches thick and three 3-1/2 inches thick, were made using the formulation listed in Table I; two plots of each CMC percentage were made, one of each thickness. For each batch, the foam was mixed in a 55-gallon drum, yielding approximately 50 gallons of raw liquid. The foam was applied to the plot through a hose and spreader; however, it tended to emerge in spurts rather than a steady stream (Figure 2). As soon as sufficient foam was on the plot, as judged by eye, the plot was leveled with the use of a straight-edge moved along flush with the tops of the confining boards (Figure 3).

The arrangement of the plots is shown in Figure 4. The order of foaming is indicated by the batch number. Plots 2, 4, and 5 were not completed immediately; these were completed 2 to 3 hours after the initial application, with the addition of batch 11 to plot 2, batch 12 to plot 4, and batches 8, 9, and 10 to plot 5. Shortly after foaming of each batch was begun, a sample was taken in order to determine the expansion ratio of the foam (Table II). This was determined from the known weight of the original solution and the weight of the foam. The test plots were observed for shrinkage and deterioration 1, 2, 3, 6, and 8 days after the foam was laid down.

In addition, three 6- by 10-foot plots were constructed with a 3-inch thickness, using one of each foam formulation listed in Table I. These were prepared in the same manner as those mentioned above and the expansion ratio of this foam was also determined (Table II). The forms were removed from these plots shortly after they were constructed and the plots were used for trafficability tests 4 hours later. The traffic plots were trafficked with a 1-1/2-ton truck 4 hours and 1, 2, 5, and 7 days after the foam was laid down. A truck was used because it was the most convenient method even though it was less detrimental than aircraft.

Weather

During the foaming of these plots, from about 0800 to 1400, air temperatures averaged 75 F and relative humidity averaged 77 percent; average relative humidity for the 24-hour period was 83 percent. Total solar radiation for the 24-hour period or for the foaming period, was not available, but the average solar radiation for daylight hours, 0500 to 1900, during 1951, 1952, and 1954 (years for which solar radiation information was available) was 0.67 gm cal/cm^2 min. Average solar radiation for the 9-day period of application and observation

was 0.68 gm cal/cm^2 min using the 3-year period values. Average relative humidity for the 9-day period was 82 percent.

The average solar radiation for daylight hours at Port Hueneme is 1-3/4 times the average solar radiation of 0.37 gm cal/cm^2 min for daylight hours (24 hours) at Point Barrow. However, if the Port Hueneme values are averaged over a 24-hour period, they are only slightly greater than the Point Barrow values of 0.393 gm cal/cm^2 min. Consequently, although the daylight hour radiation compares favorably with the laboratory test radiations of 0.41 and 0.78 gm cal/cm^2 min, the radiation was effective only during 58 percent of each 24-hour period, while the laboratory test radiations and the Point Barrow radiations were effective 100 percent of each 24-hour period.

Foam Durability

At the time of leveling of the foam, some air bubbles were present and were elongated during leveling. These elongated bubbles were as large as 2 by 1-1/2 inches. Within 1/2 hour after completion of each plot, broken air bubbles and blisters became very noticeable on the surface of the foam (Figure 5). The blisters were formed by air bubbles up to 3/4 inch in diameter. As the foam began to dry, the blisters were no longer noticeable. On the 0.75 percent CMC plots, the surface took on a spongy appearance; the 1.25 and the 1.75 percent CMC foams formed a crust. Although the foam was very white when foamed, it turned brown as it dried; the foam with a higher CMC percentage had a darker color.

The plots on which completion was delayed had begun to dry and were already turning brown when the final foam was added either on top of the earlier foam or on sand. The high solar radiation of 0.67 gm cal/cm^2 min for daylight hours probably accounted for most of this drying since the following morning, the added foam was not as dry as the initial foam had been the previous afternoon, although it had been in place 3 times longer. This indicates that the radiation had more effect on the drying of the foam than did any effect of the sand.

As the foam aged and dried, it began to crack, apparently from shrinkage as it also decreased in thickness. According to laboratory tests, the foam should have decreased slightly in thickness as it dried completely in a cellular consistency. Eventually, the foam completely dried up, at which time it pulled together into tufts with approximately 75 percent of the sand exposed between tufts. The main difference in plots was the time it took to dry. Figure 6, which illustrates the stages of deterioration, is a general view of the

4-inch-thick plots 3 days after application. In the foreground (plot 5) is the recommended formulation of 1.75 percent CMC which shows a number of cracks, although not as many as the middle plot. The middle plot (plot 3) is the 1.25 percent CMC formulation. This plot had many cracks, but at this time it had not dried up enough to show the sand beneath. The far plot (plot 1), the 0.75 percent CMC formulation, is completely dried up with only tufts of foam left on the sand. A more detailed description of each plot is given in Table III.

Close-up views of the foam are illustrated in Figures 7 through 10. Plots 2, 3, and 5 are shown approximately one day after application in Figures 7, 8, and 9. In these figures, the differences in cohesiveness and lasting ability of the foam are illustrated. Figure 10 of plot 6, six days after application, illustrates the general appearance of all plots at this time. Notice how the underlying sand is visible over about 3/4 of the area. Observations were terminated 8 days after these plots were foamed as the foam was completely deteriorated. This was approximately 1/3 the length of time the foam lasted at Point Barrow.

Foam Trafficksbility

The first traffic tests were run on all three CMC percent foams while they were still wet, 4 hours after they were foamed. The 1-1/2-ton truck was driven forward over the foam and then backed up, at a maximum speed of 5 mph. When the tires rolled over the foam, it stuck to the tires until they were covered; little more was then picked up (Figure 11). Where the foam was quite wet and still several inches thick, some adjacent foam would flow in to fill the tire marks. Properly cured, the foam should have been stiff rather than flowing. As the foam dried, it would continue to stick to the tire, but less and less would flow into the tire marks.

This is illustrated by Figure 12 where the 0.75 percent CMC foam to the left was wet enough after 4 hours to stick to the tire but dry enough so that it did not flow into the tire marks. The other 2 foams were still wet enough to flow into the tire tracks. When the foam was completely dried, it was merely crushed under the tires and none would stick.

Within 1 day of foaming, the 0.75 percent CMC foam was completely dry; the 1.25 percent CMC foam lasted 5 days, and the 1.75 percent CMC foam, 7 days (Figure 13), before becoming completely dry. A more detailed description of each plot is given in Table IV. Observations were terminated 7 days after the traffic plots were first foamed.

FINDINGS

1. Expansion ratio of the foam decreased with an increase in CMC-7HP stabilizer. The batch generator was not capable of producing an expansion ratio of greater than 5.4:1 using the recommended formulation of Mearlfoam-5 stabilized with 1.75 percent CMC-7HP.

2. The recommended formulation of 1.75 percent CMC stabilized foam lasted longer than those foams with less stabilizer, but did not last longer than 8 days even when expanded to a maximum of 5.4:1.

3. Moist foam stabilized with any of the 3 percentages of CMC stuck to the tires of a 1-1/2-ton truck; dried foam was crushed by the tires. Very moist foam flowed into the areas emptied of foam by tires.

4. The Port Hueneme foam never set up as it had in laboratory tests.

5. Precise control over the mixi g of the ingredients and the expansion ratio could not be maintained using the batch generator with hand mixing of the ingredients.

6. While the Port Hueneme tests did not consider all field conditions, they did indicate the performance of the foam under curing conditions.

CONCLUSIONS

1. Aqueous foam stabilized with CMC-7HP is difficult to generate and needs precise control of the mixing and foaming of the ingredients.

2. To be properly evaluated, the CMC stabilized foam requires a complete system rather than a batch generator.

ACKNOWLEDGEMENTS

The author is indebted to Dr. C. W. Terry for his assistance with the design of the generator, and for writing the Appendix on the description of the generator.

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3. U. S. Naval Civil Engineering Laboratory. Technical Note N-477, Protective Coverings for Sea Ice, by N. S. Stehle. Port Hueneme, California, December 1962.

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5. Hercules Powder Co. Hercules Cellulose Gum Properties and Uses. Wilmington, Delaware, July 1960.

APPENDIX

Description of Foam Generator

The batch generator (Figure 14) was in two sections: a liquid mixer and a foam pump. Mixing of the water, powder stabilizer, and liquid foam was accomplished in a 55-gallon drum by recirculation of the liquid through 2-inch-diameter piping. Short, large-diameter piping and a minimum number of fittings were used between tanks and pumps in order to reduce friction and cavitation. The drum was filled with approximately 50 gallons of fresh water[2] which was then recirculated. The CMC and aluminum acetate powders were then introduced into the water through an air ejector. A partial vacuum was created in the ejector by compressed air flowing through; this caused induction of the powders into the water which circulated through the inductor. Mechanical agitation of the liquid in the drum was provided by an 8-inch-diameter radial vane impeller centrally positioned about 8 inches above the bottom of the drum; the impeller was powered by a 1-hp air motor. After all of the powder was dissolved, the Mearlfoam-5 liquid was added directly to the drum and recirculation was continued for about 2 minutes. Agitation was continued during recirculation and discharge until the liquid level in the drum reached the impeller.

Upon discharge, recirculation was stopped and the discharge line was opened. Compressed air was introduced into the foam and the two mixed in a modified Penberthy injector, which introduced several small streams of air into the liquid and to give positive, vigorous agitation to the liquid. Excess air was used to achieve maximum expansion of the foam. The foamed liquid then flowed through a 12-inch-long, 4-inch-diameter refining section of pipe filled with assorted sizes of ceramic rings and then into a centrifugal pump. The foam was further mixed here and then forced through a 50-foot length of 2-1/2-inch-diameter flexible discharge hose. A flat nozzle (Figure 2) was used to assist in distributing the foam. From calibration curves of the pumps, speeds were set with a tachometer to assure attainment of the desired discharge capacity.

Table I. Foam Formulations for the Port Hueneme Tests.

Material	Amount (weight percent)		
	Plots 1,2,1B*	Plots 3,4,2B	Plots 5,6,3B (Recommended Formulation)
Mearlfoam-5	6.7	6.7	6.7
CMC-7HP	0.75	1.25	1.75
Aluminum acetate	0.075	0.125	0.175

* B indicates the traffic plots

Table II. Expansion Ratio For Each Test Batch at Port Hueneme.

CMC (percent)	Batch No.*	Plot No.	Expansion Ratio
0.75	1	1	7.42
	2	1&2	6.15
	11	2	5.30
	1B**	1B**	5.03
	average		5.98
1.25	3	3	4.57
	4	3	4.17
	5	3&4	4.19
	12	4	3.78
	2B	2B	5.79
	average		4.50
1.75	6	6	2.46
	7	5&6	5.35
	8	5	4.77
	9	5	2.89
	10	5	2.86
	3B	3B	4.40
	4B	3B	4.63
	average		3.91

* Indicates order of foaming.

** B means traffic plots.

Table III. Relative Foam Durability in the Port Hueneme Tests.

CMC (percent)	Original Thickness (inches)	Approximate Time After Application (Days)				
		1	2	3	6	8
0.75	3-1/2	Dried to fat tufts, much sand visible.	----------	----------	----------	----------
0.75	1-3/4	Tufted and cracked, little sand visible.	Dried to thin tufts, much sand visible.	----------	----------	----------
1.25	3-1/2	Weak crust, many cracks.	Surface down 1-1/4 to 2 in. from original, dry crust, wet beneath, many cracks.	Down 3 in., almost all dry, many cracks and holes.	Dried to broken film, much sand visible.	----------
1.25	1-3/4	Slight weak crust, many cracks.	Surface down 1-1/4 to 1-3/4 in., some sand showing, dry crust.	Dried to broken film, much sand visible.	----------	----------
1.75	3-1/2	Firm crust, few cracks and holes.	Down 1 in. in center area, firm dry crust, cracks dry but fragile foam, wet beneath, few wide (¼ to ½ in.) cracks, mod. no. small.	Wide cracks getting wider, mod. to many smaller cracks, down 1 to 1½ in.	30% sand showing, foam dried.	Dried to broken film and tufts, 75% sand showing.
1.75	1-3/4	Firm crust, mod. to many cracks.	Dried crust, mod. no. cracks ¼ to ½ in. wide & sev. in. long, down 1¼ to 1½ in. in center, some sand visible.	Down 1-1/2 to 1-3/4 in., sand visible in sev. spots, 1/4 plot dried to broken film with much sand visible.	Dried to broken film and tufts, much sand visible.	----------

Table IV. Foam Trafficability With a 1-1/2-Ton Truck on the Port Hueneme Test Plots.

CMC* (percent)	Approximate Time Since Application (Days)				
	1/4	1	2	5	7
0.75	1-1/2 in. thick, all foam stuck to tire, sand remained clean.	Dry, crushed by tire	----------	----------	----------
1.25	3-in. thick, some foam stuck to tire, foam flowed into tire tracks.	Same as 1/4.	All foam stuck to tire; sand left clean.	Dry, crushed by tire.	----------
1.75	Same as 1.25%	Same as 1/4.	Same as 1/4, except not as much liquid foam flowed into tracks.	All foam stuck to tire; sand nearly clean.	Dry, crushed by tire.

* 3-inch original thickness.

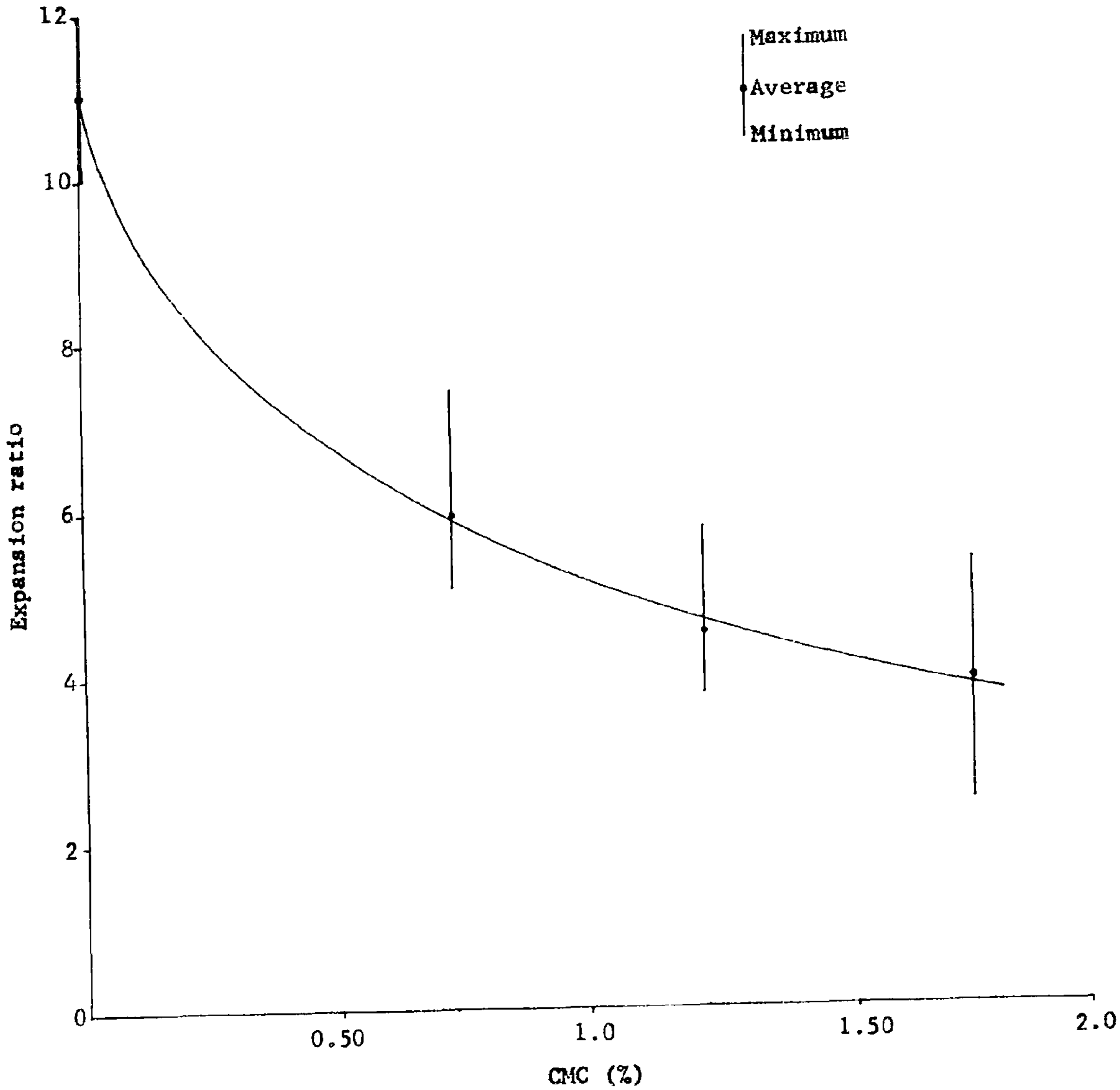


Figure 1. Effect on the expansion ratio of increasing CMC percent.

Figure 2. Spurting of foam from applicator.

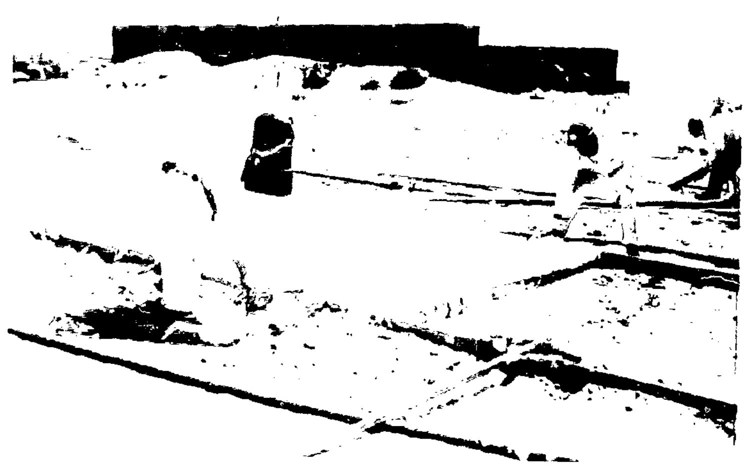
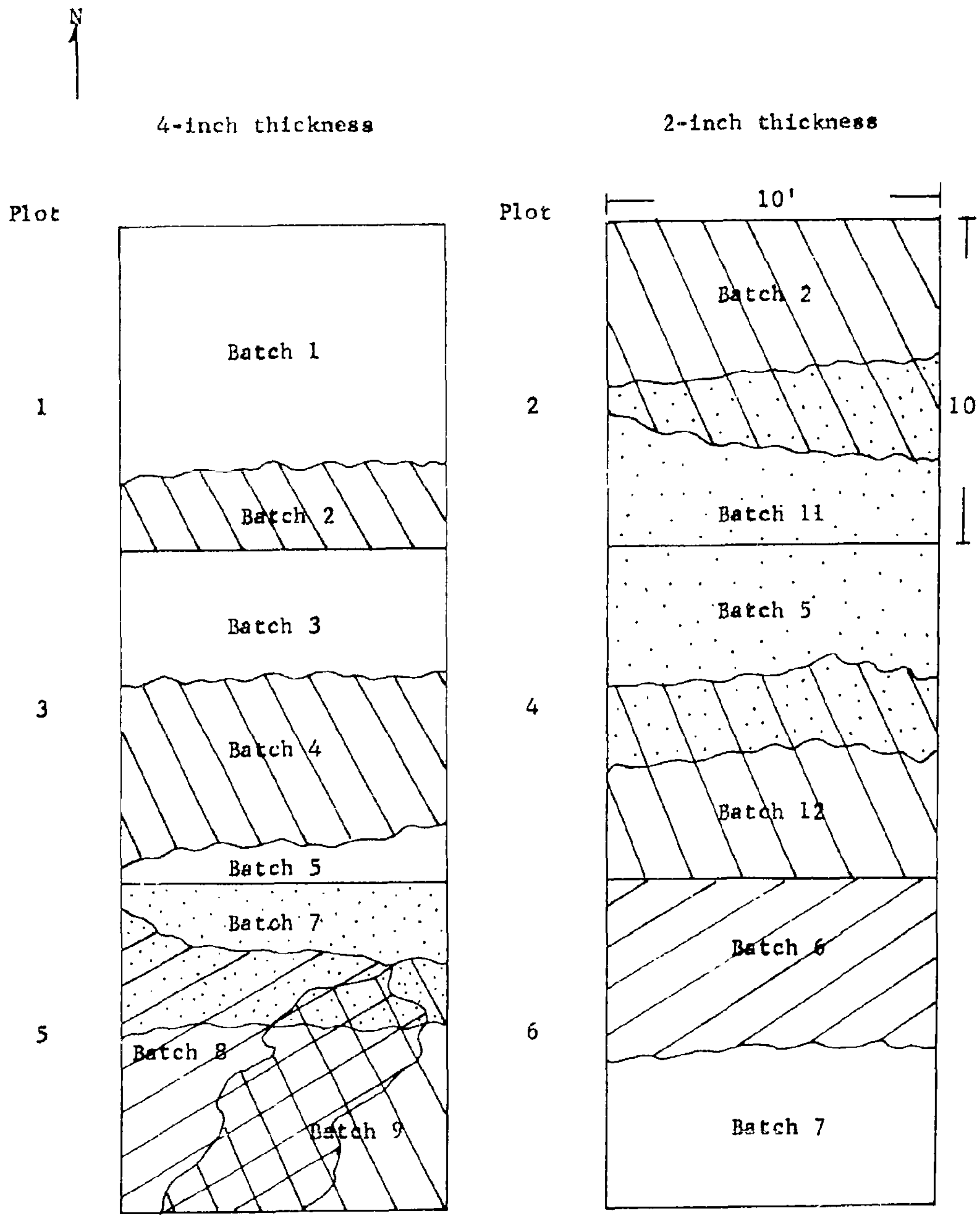


Figure 3. Leveling plot surface.



Note: Batch 10 was spread over Plot 5.

Figure 4. Layout of plots.

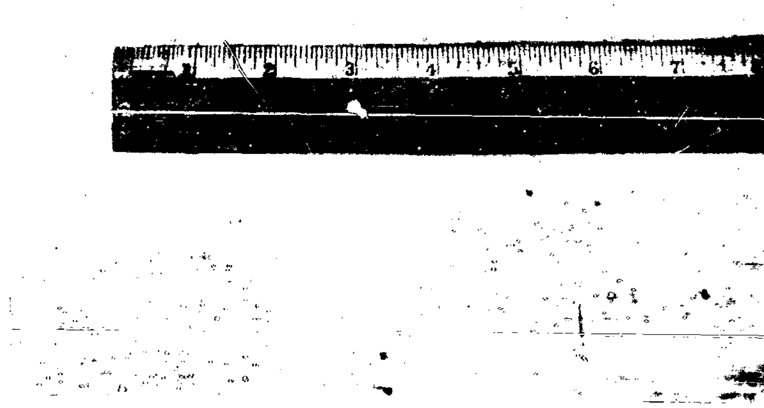


Figure 5. Air bubbles on surface.

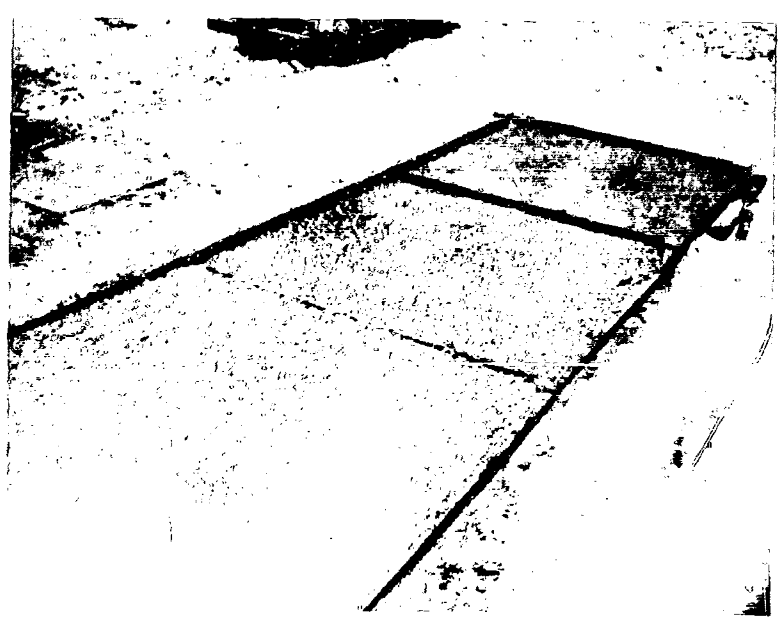


Figure 6. General view of 4-inch-thick plots
3 days after application.

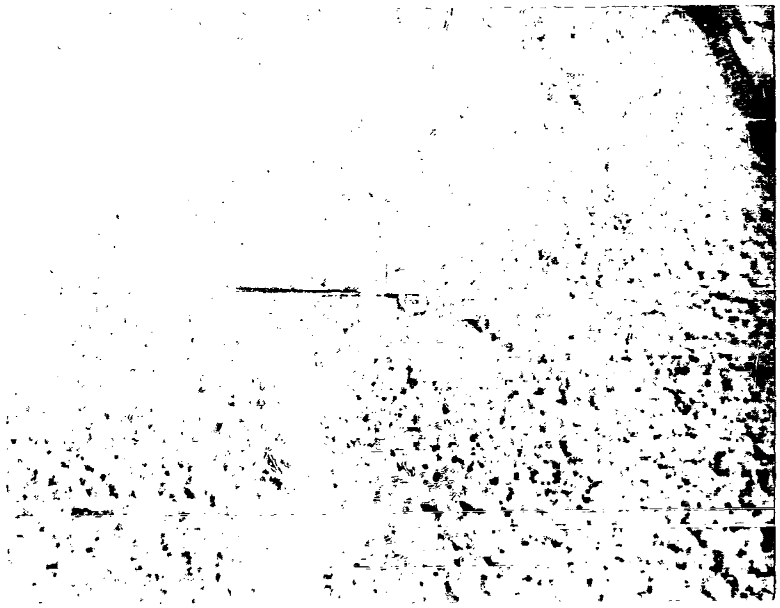


Figure 7. Plot 2 one day after application.

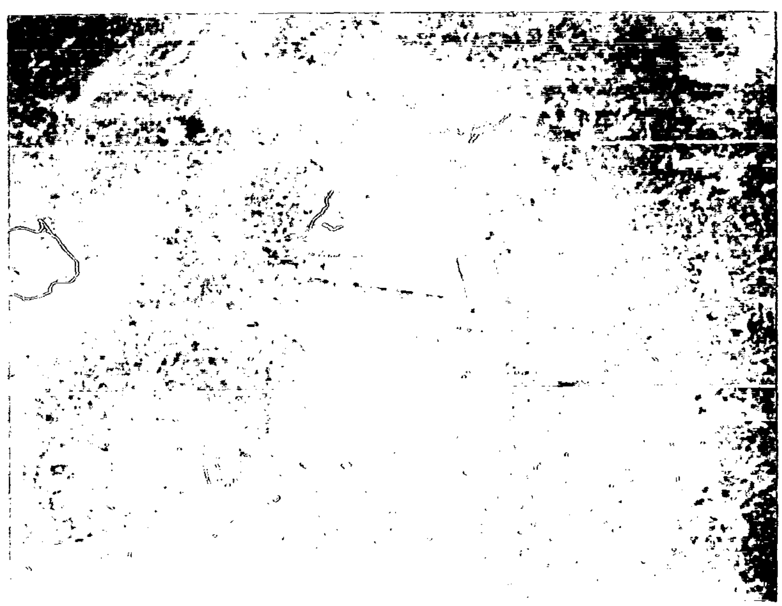


Figure 8. Plot 3 one day after application.

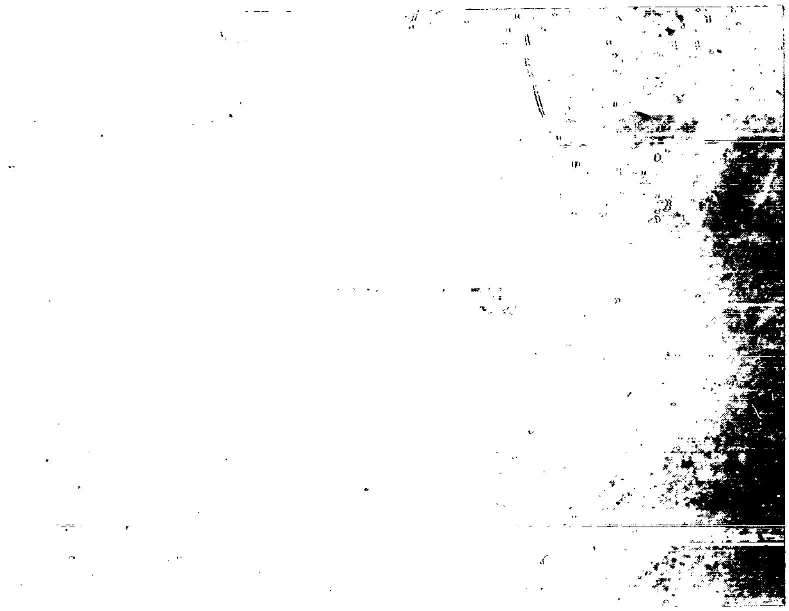


Figure 9. Plot 5 one day after application.

Figure 10. Plot 6 six days after application.

Figure 11. Trafficked plot 4 hours after application immediately after trafficking.

Figure 12. Foam covered tire.

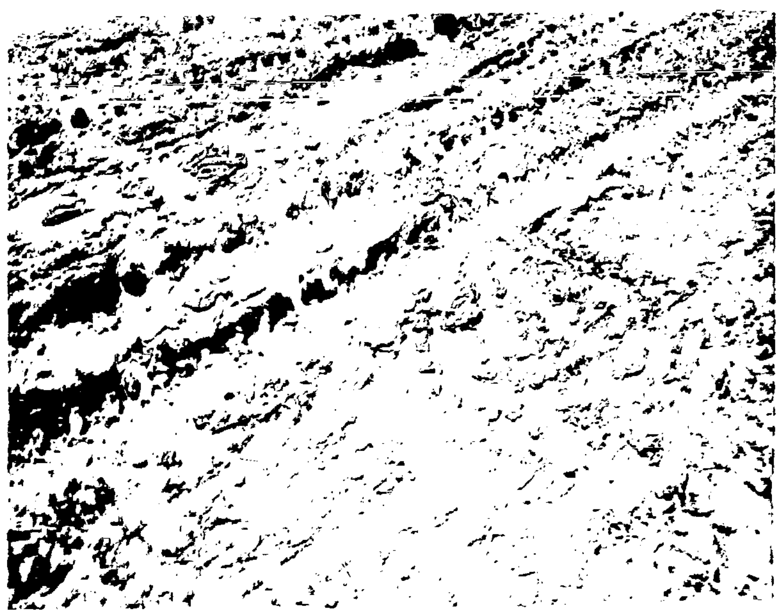
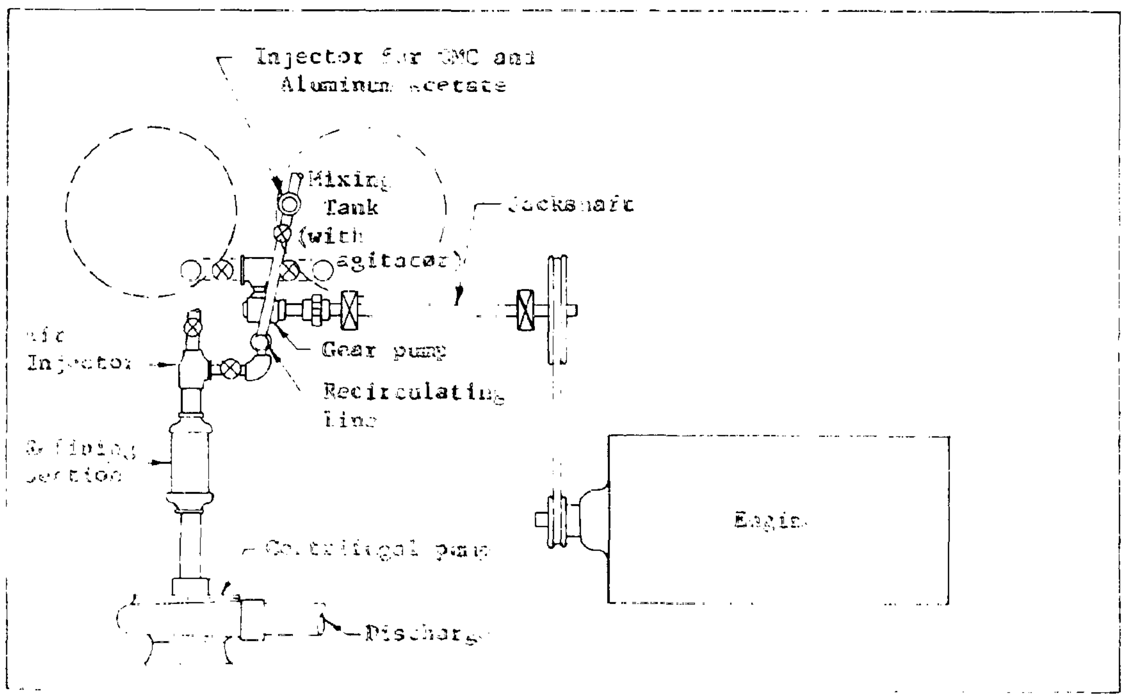


Figure 13. Traffic plot, 1.75 percent CMC foam, 7 days after application, immediately after trafficking.



Diagrammatic Layout of Foam Generator.

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